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REPORT ON THE UNITED NATIONS/EUROPEAN SPACE AGENCY TRAINING COURSE FOR LATIN AMERICAN AND CARIBBEAN COUNTRIES ON THE MONITORING OF NATURAL RESOURCES, RENEWABLE SOURCES OF ENERGY AND THE ENVIRONMENT USING DATA FROM THE EUROPEAN REMOTE SENSING SATELLITE

(18-28 April 1994, Frascati, Italy and 29 April 1994, Rome)

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INTRODUCTION

A. Background and objectives

1. At its thirty-seventh session, the General Assembly adopted resolution 37/90 of 10 December 1982, in which it endorsed the recommendation of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82) that the United Nations Programme on Space Applications should, inter alia, promote the growth of indigenous nuclei and an autonomous technological base in space technology in developing countries, as well as promote greater cooperation in space science and technology between developed and developing countries as well as among developing countries.

2. The Committee on the Peaceful Uses of Outer Space (COPUOS), at its thirty-sixth session in June 1993, endorsed the activities of the United Nations Programme on Space Applications for 1994 as proposed by the Expert on Space Applications (A/AC.105/555) and as recommended by its Scientific and Technical Subcommittee at its thirtieth session. Subsequently, the General Assembly, in its resolution 48/39 of 10 December 1993, endorsed the activities of the Programme on Space Applications for 1994.

3. In response to Assembly resolution 48/39, and in accordance with the UNISPACE 82 recommendations, the Programme on Space Applications included, as part of its activities for 1994, the organization of a Training Course for Latin American and Caribbean Countries on the Monitoring of Natural Resources, Renewable Sources of Energy and the Environment using Data from the European Remote Sensing Satellite (ERS-1). This Course was the second in a series following a similar one organized in 1993 for the benefit of African Francophone countries (A/AC.105/556/Add.1).

4. The United Nations/European Space Agency Training Course for Latin American and Caribbean Countries on the Monitoring of Natural Resources, Renewable Sources of Energy and the Environment using Data from the European Remote Sensing Satellite (ERS-1) was organized jointly by the Programme on Space Applications, Office for Outer Space Affairs, and by the Department for Development Support and Management Services in cooperation with the European Space Agency (ESA).

5. The objectives of the Course were (a) to provide participants from Latin American and the Caribbean countries with a theoretical basis and practical experience in various aspects of microwave remote sensing, focusing on the applications of that technology to natural resources, sources of renewable energy and, in particular, its use in conducting inventories and monitoring the environment; and (b) to familiarize the participants with the operational services of ERS-1 (e.g. data coverage, data sources and products processing levels), bibliography and archive of ERS-1 materials and data that are available at the European Space Research Institute (ESRIN) facility at Frascati, Italy.

B. Organization and programme of the Course

6. The Course was held from 18 to 28 April 1994 at the ESA/ESRIN facility. The final session and closing ceremony of the Course was held on 29 April 1994 at the Headquarters of the Istituto Italo-Latino Americano (IILA) in Rome. The Course was attended by 24 participants from the following 19 countries: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Uruguay and Venezuela. Financial support to defray the cost of air travel and living expenses of the participants was provided by the United Nations Trust Fund for New and Renewable Sources of Energy. The programme for the Course was developed jointly by ESA and the United Nations (Office for Outer Space Affairs). The lecturers for the Course came from France, Spain, ESA and the United Nations (Office for Outer Space Affairs).

7. The Course provided participants with the physical theory on which remote sensing, both active and passive, is based. The Course presented an overall view of remote sensing in various intervals of the electromagnetic spectrum, including the visible, infrared and microwave regions and highlighted the multidisciplinary nature of the use of the data. Since the ERS-1 payload is composed mostly of active radar instrumentation, the Course emphasized active microwave remote sensing. The Course included the theory and concepts of Synthetic Aperture Radar (SAR) image formation as well as an introduction to digital image processing of radar data in oceanographic, geologic, hydrological, topographic and cartographic applications. The Course also provided the participants with examples of the applications of the data received from various of the instruments on-board ERS-1 as well as with hands-on experience in digital processing of microwave image products. The complementary information that can be obtained from optical and radar data was stressed as a powerful asset for remote sensing. Presentations made by the lecturers included case-studies of programmes or projects conducted in Latin America.

8. The United Nations and ESA utilized the presence of individuals representing institutions from 19 countries in the region of Latin America and the Caribbean to further develop the concept of a programme proposal that could provide satellite data for institutions in developing countries. This concept had originated during the first course held at Frascati in 1993 for African Francophone countries. The concept that was discussed and the work that was conducted by the participants and co-sponsors of the Course are summarized in the section that follows.

9. The present report, which covers the background, objectives and organization of the Course as well as giving a summary of the technical presentations (see annex to this report for the programme of the Course), has been prepared for COPUOS and its Scientific and Technical Subcommittee. The participants in the Course have reported on the knowledge acquired and on the work that they conducted during the Course to the appropriate authorities of the Government, universities and research institutions in their own countries.

I. POSSIBILITIES FOR THE ACQUISITION OF SATELLITE DATA

A. Background

10. Together with satellite systems of other national agencies, the remote sensing satellites (ERS) of ESA contribute to observing the Earth and its environment in a systematic, global and accurate manner. Through modern technology they provide measurements of physical parameters of the ocean-land-atmosphere system with continuity, compatibility and full coverage, night and day. Where supported by operational ground acquisition stations, they ensure long-term observations and therefore they make available time series of consistent and calibrated remote sensing data. This allows the building up of a history of parameters describing a physical phenomenon such as climate. From such a history, characteristics, trends and anomalies of the phenomenon could be identified.

11. Due to the capability of microwave radiation to penetrate clouds, ERS provide all-weather images of the Earth surface and allow the monitoring of surface features even in areas where optical instrumentation fails because of frequent or permanent cloud coverage, such as over equatorial and polar regions. In addition, radar images provide information on surface geometry and humidity which significantly complements surface albedo and temperature data provided by optical satellites, making remote sensing observations a very powerful and versatile tool for applications to environmental disciplines. The nature of such satellite data is in effect multidisciplinary, since they can serve at the same time many applications and different operational requirements. Directly or through ESA services, national institutions may gather this data, archive them and, if required, further process them to serve their users in fields as diverse as geology, oceanography, hydrology, meteorology, glaciology, forestry, agriculture, topography, cartography, land use and environmental fields spanning from urban settlement to pollution monitoring.

12. During the Course held in Frascati in 1993, the participants indicated that two obstacles to their utilization of image products, such as those they had learned to use at the Course, were the lack of access to them and a need for further education on the principles of their use along with hands-on training to develop experience in the mechanics of their analysis. The representatives of the Secretariat and ESA had indicated that they would explore ways and means through which at least a limited amount of data and further training could be provided for use in the ongoing activities of the participants.

13. Between May 1993 and April 1994, representatives of the Office for Outer Space Affairs, Department of Development Support and Management Service of the United Nations and ESA discussed the issue and concluded that (a) for the courses to reach their objectives fully, it was essential that participants in the Training Course on their return home should have access to satellite data and to the necessary image processing software in order to strengthen their newly acquired skills; (b) institutions with ongoing projects would be the most likely to need and utilize the data; and (c) a programme proposal could be developed by the co-sponsors for capacity building and institution strengthening through which a limited amount of data, necessary software and further training could be provided to some institutions in the developing countries.

14. The development of the programme would include the following three phases: (a) needs assessment to determine the degree of interest of institutions in the regions participating in the programme and the quantities and types of data needed; (b) identification of ongoing projects in Africa and in Latin America and the Caribbean that are using or could use satellite data; and (c) selection of projects on the basis of those remote sensing applications that were in greatest demand in the regions concerned. Subsequently, the programme would be presented by the co-sponsors, with the endorsement of the institutions and their Governments, to potential funding sources. The data that the programme would provide would not be limited to ERS-1 data but, on the basis of the requirements of the projects, could be from other satellites (e.g. LANDSAT, SPOT) or from a combination of them in order to take advantage of the complementary nature of satellite-obtained data.

B. Preparatory work conducted by participants

15. The above-mentioned concept was presented to the participants in the 1994 Course in Frascati along with an invitation to contribute to the first two phases of the programme. The participants expressed great interest in the offer and decided to invest time after the conclusion of each day's meeting to conduct a survey among themselves on the issues related to phases (a) and (b) described above. The United Nations and ESA provided additional information and assisted the participants in their work.

16. At the conclusion of the Course, a meeting was held at the headquarters of IILA in Rome, attended by representatives of the embassies in Rome of the countries of the participants, at which the participants presented their findings, as follows:

(a) Very few institutions have radar images and even fewer have personnel with a working knowledge of their use. In some cases the images exist at institutions but the software to process them is not available;

(b) Radar images are sources of new and useful information, particularly for tropical areas which are frequently covered by clouds. However, their potential is better utilized when combined with images obtained by the optical-infrared sensor systems on board satellites such as LANDSAT or SPOT;

(c) Projects in nine thematic areas are being conducted by the institutions represented by participants at the Course. These areas are geology, agriculture, oceanography, glaciology, hydrology, geodesy and geodynamics, risk of natural disasters, meteorology and development of software to process radar data;

(d) Participants identified 42 areas located in 18 countries of Latin America and the Caribbean where institutions from at least three countries have ongoing projects in application areas with similar objectives.

The participants provided a copy of this report to the co-sponsors.

17. The United Nations and ESA informed the participants that the co-sponsors would conduct a complementary needs assessment campaign for the region as a preparatory phase to preparing the programme proposal referred to above. The co-sponsors would keep the participants and their institutions informed on the progress that was made.

II. SUMMARY OF PRESENTATIONS

A. Fundamentals of remote sensing

18. Electromagnetic radiation incident on an object on the surface of the Earth interacts at the atomic and molecular level with the object. The portion of radiation that is reflected in the direction of a remotely placed sensor carries information that is intrinsic to the object. In remote sensing applications, the challenge is to identify the object given a measure of the relative amount of radiation that it has reflected. Discrimination between diverse types of objects becomes easier if measurements are done in several regions of the electromagnetic (EM) spectrum. The regions of the EM spectrum where these remote measurements are done are called "spectral bands" or simply "bands".

19. Photographic film is a sensor of electromagnetic radiation. It has been designed to represent objects approximately as they appear to the human eye in everyday situations. That is, photographic film is sensitive to radiation in the visible portion of the EM spectrum. The simplest and most inexpensive remote sensing product that can be obtained is a photographic representation of the image acquired by any type of sensor system. Such representations are generated for all sensor systems whose data have been acquired at any of a number of intervals of the EM spectrum.

20. A distinction has purposely been made in using the term "image" when referring to a representation of objects produced by a sensor which is not photographic film. Different types of sensors are used to extend detection capabilities to regions of the EM spectrum where photographic film does not respond. The type of sensors used in these regions are solid state detectors sensitive to EM radiation in specific wavelength intervals which may or may not include the visible region. In response to radiation received, detectors generate either a voltage or a current that is proportional to the amount of radiation received in their wavelength band of operation. The output signal is electronically sampled and converted to digital values that maintain a one-to-one correspondence to the original voltage or current value.

21. The digital values are stored on board the satellite for transmission to a ground receiving station. The digital data are corrected for geometric and radiometric distortions and arranged in matrix form, where each element of the matrix corresponds to the radiation received by the sensor from each resolution cell on the surface of the Earth. With the data in this form, it is possible to perform a computer-assisted analysis of the image. In order for the user to visualize the image, its range of digital values is first normalized to fall with values from 0 to 255. A correspondence is then established between those digital values and a scale of grey tones going from black to white. This makes it possible for the image to be displayed, either on a screen monitor or on photographic film, in tones of grey.

22. Since an image is only a visual representation of the data obtained by the sensor system, its appearance can be arbitrarily modified. When data from only one band is displayed, it can be done in tones of grey or

in hues of one of the primary colours (i.e. blue, green or red). If more than one band is to be displayed at the same time, each is assigned to hues of a primary colour (i.e. blue, green or red) and the user can select whether to display one, two or three bands simultaneously. Objects on the surface of the Earth appear in colours, which are a result of the superposition of the hues of the primary colours which in turn are a representation of the relative amount of EM radiation reflected by the objects in the intervals of the EM spectrum that correspond to the bands being displayed.

B. Digital image processing

23. The large potential that remote sensing from space offers is due to the following main characteristics: (a) the large surface area covered by each image; and (b) the high frequency with which data can be gathered over the same area. Once acquired, the data are only useful after an analysis has been performed to extract information from them. That is, the features that are being studied must be identified and quantified. This process is called photointerpretation when performed through visual inspection of the image. The same process is called classification when performed with the aid of a computer. In both cases the objective is the same: to identify classes of objects and to discriminate between those that are of interest to the study and those that are not.

24. The use of computers can enhance and speed the process of extracting the information. The information contained in the images is originally in digital form to facilitate its display and analysis with a computer-based image processing system. However, excellent results can be obtained from interpretation of photographic representations of the area being studied. A large number of examples of quality work using photointerpretation exist, particularly in applications such as forest management and geological mapping. At present it is possible to purchase high-quality photographic negatives or black and white/colour prints or transparencies of images at scales of up to 1:50,000. These photographic products are inexpensive and their interpretation requires simple equipment which is readily available in universities and survey and mapping institutions.

25. Digital image enhancement techniques improve the visual presentation of the information content of an image. These techniques assist in visual interpretation but do not create any new information. Common techniques include the following: contrast enhancement, spatial filtering, linear combinations of bands and principal component transformations. This step is usually done to allow the user to better identify a few areas or test fields in the image that can be used to "train" the computer during the classification process as well as to evaluate the results obtained from a classification. In the best of cases, the user has complete knowledge of the objects present on the ground in the test fields and can relate the digital values on the image to corresponding objects in the test fields.

26. Software programs which are used to discriminate the elements present in an image are called "classifiers" and fall into two broad categories, which are defined by the degree of intervention necessary by the user. The most commonly used programs are the so-called "supervised classifiers". For these, the user identifies homogeneous test fields that are representative of the classes of objects in the image. For one of the bands, the classifier calculates the mean and standard deviation of the digital values of the picture elements (pixels) in each test field. This process is repeated for each of the spectral bands included by the user in the classification process.

27. The set of values of the mean and standard deviation of a class in each of the spectral bands used become the parameters that are used to identify the pixels that belong to a particular class. This set of values is also known as the "spectral signature" of the class. When the spectral signatures of all the important classes in the image have been obtained, the program classifies every pixel in the image as belonging to one of those classes. Pixels whose spectral signatures do not match any of the ones provided are usually assigned to a catch-all class ("other"). If the evaluation of the results is not satisfactory, the user must repeat the

process by redefining the test fields and adding or removing classes. The process becomes iterative until the degree of accuracy is achieved.

28. Unsupervised classifiers require little interaction by the user and are based entirely on mathematical and statistical methods. While this approach makes the classification independent of specific knowledge of the area by the user, it is highly dependent on the mathematical and statistical skills of the user. In addition, unsupervised classifiers use very little of the general experience accumulated by the user in a specific field of application. Regardless of which method is used to classify satellite images, the information that is extracted is hardly ever used by itself but rather to complement or supplement information available from other sources as well as to reduce the amount of field work necessary to achieve the goals of a project.

C. Earth observation satellite systems

29. Earth observation satellites are classified as being "polar orbiting" or "geostationary orbiting" satellites. Together they form a family of satellites that cover practically all areas of the Earth (except for small regions around the poles), in a broad range of bands of the electromagnetic spectrum and with a diversity of spatial and spectral resolutions. Polar orbiting satellites are placed in low-Earth orbit a few degrees off of the poles and are Sun-synchronous (overhead passes at the same local solar time). These satellites have high spatial and spectral resolutions and long revisiting periods (on the order of days). Geostationary satellites are placed in high orbit (36,000 km) above the Earth's equator. In this particular orbit, called the geostationary orbit, the satellites rotate at the same angular velocity as the Earth so that they appear to remain stationary over the same area of the Earth. Geostationary satellites have a very high revisiting period (up to every half-hour) but their sensors have low spatial and spectral resolutions.

30. Very important geostationary satellites are the meteorological satellites (METEOSAT, GOES I and II, GMS and INSAT). These satellites are operated by a European consortium, EUMETSAT, by the National Oceanographic and Atmospheric Administration (NOAA) of the United States of America, by the Japan Meteorological Agency and by the Indian Space Research Organization and are coordinated by the World Meteorological Organization. The primary function of these satellites is to provide data for studies of meteorological phenomena, to warn of catastrophic events and to forecast weather.

31. Meteorological satellites are also placed in polar orbit from where they provide north-south coverage of the Earth. These satellites have medium spatial and spectral resolutions; higher than satellites placed in the geostationary orbit but lower than satellites that are conventionally called Earth resources satellites. Polar orbiting satellites include the NOAA/TIROS-N series, the METEOR-2 and -3 series, operated by the Russian Federation, and the FENG YUN-1, operated by China. The primary function of these satellites is also meteorological. Operational products from these satellites include rainfall estimates, hurricane classification, tropical storm bulletins, cloud-top height and cloud motion (winds) data. Data from these satellites are also being used for large-scale agriculture, oceanography and water management.

32. However, increasingly the data of polar orbiting meteorological satellites have been used for monitoring land phenomena such as the advance of desertification at regional and global scales. An instrument that has been extensively used in such studies is the NOAA Advanced Very High Resolution Radiometer (AVHRR). AVHRR is a five-spectral band scanning radiometer which provides imagery (i.e. quantitative radiance data) at both 1 km and 4 km resolutions. The data are broadcast in real time to both Automatic Picture Transmission (low resolution) and High Resolution Picture Transmission (HRPT) users. Data from AVHRR can also be recorded on board for eventual transmission when the satellite is not within the line of sight of a ground receiving station.

33. The five spectral bands of the AVHRR sensor and the applications in which they are typically used are the following:

Band 1	0.58-0.68 micrometers	Daytime clouds, snow and ice mapping.
Band 2	0.72-1.10 micrometers	Surface water delineation, vegetation and agriculture assessment.
Band 3	3.55-3.93 micrometers	Night-time cloud mapping, sea surface temperature measurement, hot spot detection (e.g. forest fires).
Band 4	10.3-11.3 micrometers	Day/night cloud mapping, sea/land surface temperature, soil moisture volcanic eruptions.
Band 5	11.5-12.5 micrometers	Sea surface temperature and soil moisture.

A linear combination of bands 1 and 2 is commonly used for vegetation index studies, in particular to monitor the advance of deserts.

34. Earth resources satellites are placed in low, nearly polar orbit and provide high spatial resolution. This resolution is typically in the range of 10-30 m and is likely to improve to 1-2 metres by the year 2000. Earth resources satellites have long revisiting periods (of the order of weeks) and cover swaths of the order of 100 km in width. Operational satellite systems in this category include SPOT-2 and -3, LANDSAT-5 and IRS-1. Sensors on board these satellites operate in the visible and near infrared parts of the EM spectrum. The products from these satellites are distributed commercially by private enterprise; in the case of SPOT, the data are distributed by SPOT Image and in the case of LANDSAT and IRS, their data are distributed by EOSAT.

35. The data from the Earth resources satellites have been progressively used in many and diverse applications since the first LANDSAT satellite was launched in 1972. Since then, the data have been used with increasing success in the following main areas:

(a) Agriculture and forestry: discrimination of crop, timber and range vegetation types, determination of crop acreage by species, timber acreage and volume by species, range biomass, vegetation vigour and stress, determination of soil conditions and associations, and assessment of damage to grasslands and forests by fire;

(b) Land-use and land mapping: classification of land uses, cartographic mapping, categorization of land capability, separation of urban and rural areas, regional planning, and mapping of land/water boundaries and transportation networks;

(c) Geology: mapping of major geologic units, igneous intrusions and recent volcanic deposits, recognition of rock types, search for surface indications of mineralization and determination of regional structures;

(d) Water resources: determination of surface-water area and volume, mapping of floods and plains, determination of snow and ice areas and boundaries, sediment and turbidity patterns including water depth and delineation of irrigated fields;

(e) Oceanography and marine resources: detection of living marine organisms, of turbidity and circulation patterns, mapping of shorelines, shoals, shallow areas and their changes, mapping of ice for shipping routes and studies on global phenomena such as El Niño;

(f) Environment: mapping and monitoring of land, air and water pollution, surface mining effects, determination of natural and man-made desertification, deforestation, eutrophication, and impact of urban and large infrastructure development.

36. Two other operational systems carry on board a combination of visible, infrared and microwave (radar) sensors. These two systems (ERS-1 and JERS-1) are operated by the European Space Agency and by the National Space Development Agency of Japan.

D. Concepts of radar remote sensing

37. Sensors that operate in the visible and infrared portions of the EM spectrum detect reflected sunlight or emitted thermal radiation and are not well suited to some types of Earth observation. This is particularly the case for tropical areas, which for large periods of time are not visible due to their cloud cover. In other situations, it may be necessary or desirable to view a region of the Earth as frequently as possible. For such cases it would be convenient to have the capability of observing the region of interest during periods in both the day and the night.

38. Microwave radiation, either emitted by the Earth due to its black body radiation characteristics or reflected from an external source such as the Sun, can penetrate cloud cover and even light rain and can also be measured during the night. There are two types of sensors that detect this radiation. These sensors are grouped into "passive" and "active" sensors depending on whether they detect radiation emitted or reflected from a natural source or whether they detect radiation that has been generated by the instrument itself.

39. Satellites that carry a radar sensor instrument on board (called radar satellites) provide their own "illuminating" source and are thus not dependent on sunlight. (The term "radar" stands for radio detection and ranging.) A radar instrument transmits short electromagnetic pulses that are backscattered by the surface of the Earth and that penetrate cloud cover with little or no attenuation. The backscattered radiation is received at the satellite and converted into an electrical signal that is suitable for recording and subsequent transmission to a ground receiving station. Radar satellites can have both imaging and ranging systems on board.

40. The main quantities that are measured by a radar instrument are (a) the time delay of the reflected signal; and (b) the intensity of the reflected signal. The first of these quantities provides the direction and distance of an object to the radar while the latter provides the orientation, geometry, roughness and dielectric properties of the object. The roughness of an object is a characteristic that depends on the wavelength of the incident radiation. If the characteristic dimension of the object is small compared to the wavelength of the incident radiation, the object is considered smooth. If the characteristic dimension of the object is approximately the same as the wavelength of the incident radiation, the object is considered rough.

41. For remote sensing purposes, an imaging radar system is carried on board an aircraft or satellite. The system consists of a transmitter, a receiver, an antenna which transmits and receives EM radiation, and a signal processing and recording unit. The transmitter generates short microwave pulses of radiation with duration of microseconds each. The pulse is transmitted by the antenna in a narrow beam into the range direction. For imaging radar systems, the geometric configuration is such that the beam is radiated from the side of the satellite at some angle of incidence to the surface of the Earth and perpendicular to the flight direction. This is called a Side Looking Airborne Radar (SLAR). More sophisticated versions of airborne radar have the same geometric configuration but utilize the concept of simulating a longer antenna by taking advantage of the motion of the satellite or aircraft and a complex sampling procedure of the returned signal. This type of instrument is called a SAR.

42. The reflected portion of the transmitted pulse is collected by the antenna and the instrument determines both the strength of the returned signal and the time delay with respect to the transmitted pulse in order to determine the range distance of the sensed object relative to the satellite. The radar beam is wide in the vertical direction and narrow in the horizontal or along-track direction. The motion of the satellite produces a two-dimensional image plane which results in a parallel and oblique view of strips of the surface of the Earth. This makes the scanning concept of an imaging radar very different from scanners that operate in the visible and infrared regions of the EM spectrum. The latter build an image of the surface of the Earth on a line-by-line basis, their viewing geometry is downward-looking and the spatial resolution of the resulting images depends on the angular resolution of the system's optics and on the altitude of the satellite or aircraft.

43. An imaging radar system has two spatial resolutions: one in the range or across-track direction and one in the along-track or azimuth direction. These resolutions depend, first on the electronic characteristics of the instrument and secondly on the geometry of the radiation incident on the surface. In the case of a SLAR, the azimuth resolution increases with increasing length of the antenna but decreases when objects are farther away from the antenna. The range resolution is determined by measuring the time delays along the slant path between reflected signals from the objects back to the antenna and increases as the time delay between transmitted and reflected pulses is shorter. For equal time delays (i.e. slant path resolution), ground resolution is better of objects farther away from the antenna.

44. For a SAR instrument, the limiting factor for their range resolution is being able to shorten the transmitted pulse while maintaining sufficient power to detect the reflected signal. A SAR system maintains the range resolution by transmitting more energy through a technique known as "chirping" whereby the transmitted pulse is modulated by a signal whose frequency increases (or decreases) linearly in time instead of through a sinusoidal modulation. Through a Doppler effect analysis of the reflected signals, the motion of the radar platform is used to improve the azimuth resolution and to make it independent of the distance of the object to the antenna and of the frequency of the incident radiation. This results in a constant resolution in the azimuth direction which is much better than that in the case of a SLAR.

45. In radar image formation, the first return pulse corresponds to the object whose projected distance in the direction of the sensor system is the smallest. In general, this pulse corresponds to the object closest to the flight path. Because of the geometry of the incident pulse and the height of objects, the projected distance in the direction of the sensor system of the upper part of an object is smaller than the distance of its corresponding ground projection. This effect is known as foreshortening and makes terrain of high relief appear in the image as falling towards the radar. On the images, foreshortening causes the slopes to become extended and to appear darker. This effect can be corrected with reference to a digital terrain map.

46. The foreshortening effect can become very severe so that the top of a mountain appears to be closer to the flight path than the foot of the mountain. This effect is called layover and cannot be corrected. Other image degradations include speckle effect - which appears as a noise on the image although strictly speaking it is not and is related to the frequency coherence of the system - as well as several effects due to the motion of the object with respect to the sensor or to other objects in the field of view of the radar.

47. The microwave spectrum is subdivided into various bands, each of which is referred to by a single letter and is determined by a range of frequencies as follows:

Band name	Band interval (GHz)	Band name	Band interval (GHz)
P-Band	0.225-0.390	K-Band	10.90-36.00
L-Band	0.390-1.550	Q-Band	36.00-46.00
S-Band	1.550-4.200	V-Band	46.00-56.00
C-Band	4.200-5.750	W-Band	56.00-100.0
X-Band	5.750-10.90		

For airborne radar missions, the most used bands have been the X-Band, L-Band and K-Band. For the satellite radar systems, current and those to be launched by the turn of the century, the predominant frequency is C-Band.

E. Sources of satellite radar data

48. The European Remote Sensing Satellite-1 (ERS-1) was launched in July 1991 and carries several microwave sensors on board. Its primary instrument is the Active Microwave Instrument (AMI), which can provide high-resolution images (in C-band), wind speed through ocean wave spectra analyses and the length and direction of waves. While in an imaging mode, AMI covers a swath of 80-100 kilometres, with a resolution to the order of 27 metres in the range direction and 29 metres in the azimuth direction.

49. Operating in the wind mode, AMI covers a swath of 400-500 km over the ocean with resolution cells of 50 km and measures wind speed in the range of from 4 to 24 m/s with an accuracy of from 0.5 m/s to 2 m/s. Wind speed and direction are determined by measuring the strength of the backscattered signal of each resolution element from three directions: obliquely ahead, to the side and obliquely behind the satellite path. The intensity of the three signals provides the wind speed, and the differences between them indicate the wind direction with an accuracy of 20°. In wave mode operation, AMI determines the length and direction of ocean waves in 5 x 5 km cells for segments of 200-300 km along the satellite path. Ocean wave lengths of 100-1,000 m can be measured to an accuracy of 25 per cent.

50. ERS-1 also carries a Radar Altimeter (RA) that operates on a wavelength of 2 cm. This altimeter is used to measure average wave height, wind speed and to determine meso-scale ocean topography. Data from this altimeter have been used successfully to determine ice type and topography as well as the water/ice boundaries.

51. A third instrument on board ERS-1 is the Along Track Scanning Radiometer (ATSR) that operates in three bands in the thermal region of the EM spectrum. These bands are centred at 3.7, 11 and 12 micrometers. ATRS looks through the atmosphere at the surface of the ocean from two directions, downwards vertically and at an incidence angle of 50°. The difference between the oblique and vertical measures provides information on atmospheric absorption while the differences between measurements at the three wavelengths are used to determine atmospheric water vapour content.

52. The three instruments described above were designed primarily for ocean observations. Of the three, AMI, in its imaging mode, has been finding the greatest number of applications for land monitoring, surveying and exploration. In particular, its SAR images have been tested, with varying degrees of success, in agriculture, forestry, hydrology, cartography, geology and for monitoring natural hazards such as floods and mud-flows. Near the coastline, SAR images have found applications to aquaculture, mangrove forestry and coastal monitoring (coastline, erosion, tidal flows and effects of dams).

53. Launched in 1992, the Japanese Earth Resources Satellite (JERS-1) is also equipped with a SAR sensor. However, this sensor system operates in the L-Band (0.390-1.550 GHz). JERS also carries a Visible and Near Infrared Radiometer (VNIR) and a Short Wavelength Infrared Radiometer (SWIR); both instruments provide a spatial resolution of 18 m x 24 m. This satellite is equipped with an on-board recorder for transmission of gathered data when it comes within the line of sight of one of its ground receiving stations. The revisiting period for this satellite is 44 days.

54. JERS-1 has been placed in Sun-synchronous orbit and its data is received by the Hatoyama Observation Center and by several other receiving stations around the world. This satellite conducts a variety of observations, not only for resources exploration but also for land survey; agriculture, forestry and fishery; sea-ice monitoring; environmental monitoring; disaster prevention; coastal monitoring; and other applications.

F. Calibration and validation of image products

55. Microwave techniques involve sophisticated processing of the return signals to derive geophysical parameters. The calibration of the instruments and long-term verification of geophysical measurements are therefore vital components of a reliable system. Thus, radar systems are periodically calibrated using ground-based artificial targets including specially designed transponders.

56. The radiometric calibration of a SAR system can establish a relationship between the intensities of an image (the numerical values of the pixels) and the backscattering coefficient of the surface being viewed. The relative calibration of a SAR makes it possible to determine the precision of a measurement compared to another measurement made on images acquired on different dates. The absolute calibration of a SAR makes it possible to determine the absolute precision of a measurement; that is, the difference between the measured value of the backscatter coefficient and its real value. This type of calibration takes into account internal factors of the instrument such as the gain settings of the instrument and of the processors.

57. For validation of the reliability of the products, the ultimate test is a direct comparison of derived estimates of geophysical parameters with the real values. Validation checks are regularly conducted to compare radar-derived estimates of surface winds and waves against actual sea surface measurements. Similar checks are conducted to determine the accuracy of the radar altimeter and of the imaging mode of the instrument.

58. For validation of ERS-1 products, the parameters that determine the quality of the images, and that are carefully controlled, are the following: (a) spatial resolution, (b) radiometric resolution, (c) radiometric calibration (relative and absolute), (d) geometric calibration and (e) phase characteristics. The treatment of parameters in the processing stage makes the appropriate radiometric corrections (taking into account the radiation pattern of the antenna) and takes into account the gain settings of the processors, verifies the linearity of the settings and utilizes adequate normalization methods. The annotations of the quality of the product, including information on calibration, are included in the format of the computer compatible tapes (CCTs) or on the photographic reproductions.

G. Radar applications to agriculture and forestry

59. The general objective of the use of remote sensing in soil, agriculture and forestry applications is to obtain information for resources inventory and management or for understanding environmental and global change phenomena. The use of radar images can complement existing information or that which might be acquired by other sensors including field data. In this sense, radar can make important contributions to: (a) identification and mapping of vegetation and soil types; (b) determination of phenological stages, deforestation, afforestation, regrowth and desertification; and (c) extraction of biophysical parameters such as biomass, vegetation density, and height and soil moisture.

60. Microwave techniques for measuring soil moisture include the use of both passive and active sensors with each having distinct advantages. Passive microwave techniques have a large area coverage since the source of the radiation is emission from the Earth itself while active systems measure only radiation reflected from the swath within the beam that has been sent by their antenna. However, active systems provide more power to the signal and can achieve higher resolutions. In addition, the choice of incidence angle of the radiation, its wavelength and polarization allows for such possibilities as gathering information from the crown of a forest or for a far greater penetration of the vegetation canopy.

61. The theoretical basis for measuring soil moisture using either active or passive microwave sensors is based on the large contrast between the dielectric properties of water and dry soil. The dielectric constant for water is of the order of 80 while for dry soils it is between 3 and 5. As a result, as water is added to soil,

the dielectric constant of the combination can change dramatically. The magnitude of both emitted and reflected microwave is dependent on the value and changes of the dielectric constant. Thus, changes in measured values in the microwave region of the EM spectrum can be directly related to degrees of soil moisture. In recent experimental results, radar backscatter responses extracted from ERS-1 SAR data have been strongly correlated to soil moisture content.

62. In contrast to water or soil/rock surfaces which have a continuous interface with air, vegetation has a discontinuous or not well-defined interface (e.g. a surface covered by leaves and air spaces). The strength of the backscattered signal can result from surface scattering (continuous interface), volume scattering (i.e. from the entire canopy) or multiple surface-volume scattering interactions. Thus, the penetration of the incident radiation, the surface roughness of the vegetation and the dielectric properties of the volume all contribute to the net backscattered radiation detected by the SAR antenna. The effects of these parameters on the measured signal depend on the angle of incidence, polarization and frequency of the radiation, and a careful consideration (or selection) of their characteristics is necessary to arrive at an accurate analysis of SAR data.

63. Incident microwave radiation of lower frequencies (i.e. longer wavelengths) penetrates vegetation more and returns information on the structure of the canopy including the trunks/stalks and possibly the soil boundary. This information is best extracted through elaborate canopy modelling techniques that perform a mathematical treatment of the physical interaction of the radiation with each class of component (leaf, trunks/stalks, soil). However, simpler analyses leading to a determination of whether the dielectric constant of the area under observation is closer to the values expected for soil than for vegetation can serve to separate sparse vegetation (low plant density and height) from dense vegetation as would be the case for various growth stages of crops. If the microwave wavelength is chosen to interact with the leaf portion of the canopy, the vegetation volumetric water content will also serve to indicate an advanced growth stage. The same technique could be used to delineate flooded from non-flooded vegetation. In the latter case, the vegetation cover might be so dense that the effect of the underlying water does not appear in the visible or infrared bands.

64. The delineation of forest and non-forest areas is generally possible in SAR images. Good results have been obtained in identifying swamp forest stands. However, the discrimination of forest clearcut and regeneration sites has been generally poor when images from only a single date or taken in a single frequency band have been used. A significant improvement has been noted when either a multi-temporal or a multi-frequency approach has been used taking advantage of change detection information. Deciduous and coniferous stands can be differentiated by the use of multiple view angles.

H. Use of radar in geology

65. Radar images have been used by geologists for more than 20 years for lineament detection and mapping as well as for oil and mineral exploration. The use of SAR images in these fields has been natural because the interaction of the radiation is to a large degree with the object of interest. That is, the rock and terrain are often exposed and not obscured by vegetation or other matter that could mask their effect on the returned signal. In addition, radar images are particularly sensitive to topographic features, surface roughness and moisture content (or to the lack of it).

66. In the case of lineament studies, the interpretation of images is done in a similar manner to the procedure used with conventional air photographs. However, the interpreter should bear in mind that the shadows seen on the image are due to the oblique incidence angle of the microwave radiation and not to solar illumination. Thus, associated effects that need to be considered are foreshortening and layover; these effects have been previously described. However, the use of images obtained at different view angles has been

found to enhance the shadow effects with the end result that they facilitate the recognition of lineaments over mountainous regions.

67. Topography enhancement is also related to the incidence view angle selected and improved results have been obtained from the analysis of several images acquired with different viewing angles. Since in general, the drainage network appears clearly on SAR images, its combined use with the topography (also derived from the SAR image) allows for a satisfactory study of the geomorphology of the area. Because of the penetrating capabilities of microwave radiation, there are examples where even subsurface structure which is part of a drainage network can be seen beneath sand-covered plains.

I. Radar altimetry for oceanography

68. The ERS-1 radar altimeter is a Ku-Band (13.8 GHz) nadir-pointing instrument designed to measure the time return echoes from ocean and ice surfaces. Functioning in one of two operational modes (ocean or ice) the altimeter provides information on significant wave height (SWH), surface wind speed, sea surface elevation (which relates to ocean currents, the surface geoid and tides) and on various parameters over ice.

69. The radar altimeter operates by timing the two-way delay for a short duration pulse that is transmitted vertically downwards. To reach the desired level of accuracy in range measurements (better than 10 cm from satellite altitude), the pulse is transmitted using the "chirping" technique mentioned above.

70. The altimeter has been designed to meet the following objectives:

(a) Global measurements of the height of the ocean waves (SWH): such measurements are very important to marine users and scientists trying to understand the ocean's dynamic behaviour. The altimeter provides data over vast regions of the oceans that did not have regular observation;

(b) Measurement of the satellite's height above the local mean sea surface: this application is used for the operational monitoring of the boundaries of major ocean currents, an activity that has significant economic benefits;

(c) Global measurements of wind speed: these values complement the wind field measurements by the AMI instrument and are used to distinguish swell from wind-driven waves;

(d) Long-term monitoring of the topography of ice sheets to provide vital warning capability for any substantial change in the Earth's climate.

71. The principle behind the functioning of the altimeter is that the information required is contained in the shape and timing of the returned radar pulse. As the incident pulse interacts with the surface of the ocean, the "illuminated" area grows rapidly from a point to a disk as does the returned power. Eventually, an annulus is formed and the geometry is such that the annulus area remains constant as its diameter increases. The returned signal strength, which depends on the reflecting area, grows rapidly until the annulus is formed and remains constant until the annulus reaches the edge of the radar beam, at which point it starts to diminish.

72. Irregularities on the surface, larger than the pulse width, cause the returned pulse to be distorted and stretched. The effect of this is to impose an additional slope on the leading edge of the returned signal strength curve. This slope is related to the ocean wave height and the mid-point of this leading edge slope is equivalent to the reflection received by the antenna of the average position of the ocean surface.

J. Use of radar to determine wind speed

73. A radar instrument can also be used to determine wind speed and direction. Through the coverage of large areas and the motion of the satellite it is possible to determine wind fields over substantially larger areas. The purpose of the wind scatterometer is to obtain information on wind speed and direction at the sea surface for incorporation into models, global statistics and climatological data sets. It operates by recording the change in radar reflectivity of the sea due to the perturbations of small ripples by the wind close to the surface. This is possible because the radar backscattered radiation returned to the satellite is modified by the wind-driven ripples on the ocean surface. Since the energy in these ripples increases with wind velocity, the signal due to the backscattered radiation also increases with wind velocity.

74. Three antennas generate radar beams that look at 45° forwards, sideways and at 45° backward with respect to the satellite's flight direction. These beams continuously illuminate a swath that is 500 km wide as the satellite moves along its orbit. Thus, three backscatter measurements of each grid point are obtained at different viewing angles and separated by a short time delay. These triplets are input into a mathematical model to calculate surface wind speed and direction.

K. Practical exercises and field trips

75. The participants in the course had several sessions of hands-on training with images from ERS-1, LANDSAT and SPOT. These practical exercises were conducted primarily on PC-based digital image processing systems. Through these practical sessions, the participants became familiar with the type of software programs that are used to perform enhancement and filtering operations on digital images. They also acquired experience in interpreting SAR images for geological, oceanographic and agricultural applications.

76. As part of the preparation for their two field trips, the participants were provided with copies of maps and images of the areas that were to be covered. Explanations of the type of terrain that would be covered and salient features to look for were also given to the participants in preparation for the trips. The instructors of the course participated in the field trips and explained why certain features that were being observed in situ appeared in a particular manner on the images.

III. CONCLUSIONS

77. During the concluding part of the Course, the participants expressed their commitment to follow-up on the work that they had conducted regarding the programme proposal that would be prepared by the United Nations and ESA. In this respect, the participants would inform the authorities of their institutions and would transmit to the co-sponsors a brief overview of the objectives and current status of their ongoing projects. The overview would include specific details on the type and quantity of satellite data that was needed.

78. The participants expressed their appreciation of the technical quality of the training programme that was prepared and delivered to them. In addition, the participants expressed their appreciation for the fellowships received from the co-sponsors, which had made their participation in the Course possible, as well as for the cooperation and support that they had received from administrative and technical personnel of ESRIN.

27 April 1994

	Application to oceanography and near-coastal areas	
09.00-10.45	Radar altimeter data for oceanography	J. Benveniste, ESA
11.15-13.15	Wind scatterometry	P. Lecomte, ESA
14.15-15.30	SAR image and wave spectrum information wind and wave models	M. Fea, E. Oriol, ESA
16.00-17.15	Practical exercises	M. Fea, J. Lichtenneger, ESA

28 April 1994

	Applications to hydrology, sea ice and glaciology	
09.00-12.30	SAR applications	M. Fea, J. Lichtenneger, ESA
12.30-13.15	Radar altimeter and scatterometer data	M. Fea, ESA
14.15-17.15	Presentation of projects	Participants

29 April 1994

09.00-10.30	Travel to IILA in Rome	Co-sponsors
10.30-13.00	Welcome to IILA Statements by authorities	
	General discussion and presentation of ongoing projects in Latin America and the Caribbean	Participants
	Certificates and closing	United Nations/ESA
14.30-16.00	Visit to the IILA exhibit	IILA